Cities as Emergent Models Ref 001

The Morphological Logic of Manhattan and Barcelona

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Abstract
This paper is set to unveil several particulars about the logic embedded in the diachronic model of city growth and the rules which govern the emergence of urban spaces. The paper outlines an attempt to detect and define the generative rules of a growing urban structure by means of evaluation techniques. The initial approach in this regards will be to study the evolution of existing urban regions or cities which in our case are Manhattan and Barcelona and investigate the rules and causes of their emergence and growth. The paper will concentrate on the spatial aspect of the generative rules and investigate their behaviour and dimensionality. Several Space Syntax evaluation methods will be implemented to capture the change of spatial configurations within the growing urban structures. In addition, certain spatial elements will be isolated and tested aiming to illustrate their influence on the main spatial structures. Both urban regions were found to be emergent products of a bottom up organic growth mostly distinguished in the vicinities of the first settlements. Despite the imposition of a uniform grid on both cities in later stages of their development these cities managed to deform the regularity in the pre-planned grid in an emergent manner to end up with an efficient model embodied in their current spatial arrangement. The paper reveals several consistencies in the spatial morphology of both urban regions and provides explanation of these regularities in an approach to extract the underlying rules which contributed to the growth optimization process.

1. Introduction: The diachronic model of city growth

This study aims to define the logic embedded in city growth in order to make explicit the generative spatial rules which contribute to the growth of cities. It investigates the possibility of an identifiable and specific logic which might be directing urban growth. The main approach in this study is to track the spatial growth of existing urban regions and investigate potential rules which drive and restrict the growth processes. Furthermore the study will undertake testing the role of distinctive elements within urban grids.

Unlike preceding research in the area of cities which concentrated merely on the phenomenological aspects of urban space, Space Syntax researchers have made significant steps towards a quantifiable knowledge of space. The studies made by Hillier and Hanson (1984) have revealed certain logic of space which has social potentials. This logic of space represents spaces as networks composed of certain spatial elements. These networks have configurations depending on the depth of a spatial element in relation to other spatial elements. Hillier and

Hanson represented each local phenomenon with a spatial element. These elements constitute a network which signifies the synchronic view of space. They have seen the local phenomenon of human's experience of space as part of a global phenomenon which represents the collective behaviour of people in cities. In this way they have revealed some abstract and quantifiable configurations of space in their studies which developed with the contribution of other researchers in the frame work of Space Syntax theory. Space Syntax theory has made clear the mathematical logic embedded in an existing spatial organization. In view of the fact that cities are diachronic models which allow changes through time, Space Syntax theory may not be limited to one synchronic view. The study contributes to previous research made in the area of Space Syntax theory by pushing the boundaries of Space Syntax studies which often concentrated on one synchronic view of space to study the diachronic behaviour of cities and the laws which govern their spatial growth. Such a study would be beneficial in terms of aiding urban design process and setting sensitive strategies to support and enhance urban growth in cities.

Cities were identified as problems of organized complexity in an argument made by Jane Jacobs (1974). They are caused by a countable set of interrelated factors which contribute in different ways to the emergent behaviour of cities. In this paper we concentrate on the spatial aspect of the organised complexity of cities by taking Space Syntax interpretation of cities as networks interconnecting spatial elements. We look at space as the main influential factor in the formation of cities. This approach might be reasoned considering Space Syntax observations which proved a correspondence approximating 70% between the spatial structure and the pedestrian movement within cities (Hillier1996a, 50). In his paper Hillier goes further to suggest that high values of spatial integration play an important role in magnifying the socio-economic activity in cities through increasing the probability of pass to and pass through movement. His ideas are based on observing land uses correspondence with the spatial structure in existing urban environments. Building on such observations, the organized complexity of cities in this study will be tackled through its spatial aspects given that space can be considered as a basic influential factor in the emergence of organized complexity. The study therefore builds upon the idea that other possible factors in the growth of cities such as historical, economical and political factors are -to some extent- more likely to be consequences of the emergent behaviour in the spatial grid.

This study has identified the synchronic view of space as a frame in time. Hence, the resulting diachronic model is constituted of a sequence of synchronic models. The diachronic model is considered as a model of spatial growth and the study aims to identify its logic and the generative rules which contribute to its emergence. Emergence laws are expected to be extracted from actual urban regions through observing transformations and mutations taking action on different grids during their spatial growth course. The results are directed to future implementations in the form of emergent city models and will be enhanced and transformed into an intelligent spatial grid using methods of optimizing depth.

2. The spatial analysis of urban grids

The current paper will be based on understanding the spatial evolution of existing urban environments and the regularities and particularities which can be extracted from the spatial morphology of cities. It will do so through testing and analysing two case studies of urban grids; Manhattan and Barcelona. It will construct a comparison between both case studies in terms of the morphological growth of their urban structures as well as the influence of a selected group of identified elements within the current state of both grids. This will imply investigating the rules and causes of emergence and growth. We will use angular segment analysis with metric radius. The angular shortest path is the one that minimizes the angle between each element and other elements. Segments are the “interjunction” stretches of streets and metric radius represents the physical distance from one element to others in the system. Background versus foreground techniques (Hillier, Turner, Yang and Park, 2007) will be also used to evaluate and capture the change in spatial structures during the growth process. In addition to these techniques we will illustrate the significance of certain spatial elements and their influence on the main spatial structure.

In the first attempt to capture the generative rules which contributed to the creation of cities several iterations of the city growth model have been redrawn and abstracted to an axial model. This axial model will be first analyzed in terms of angular segment integration using a metric radius. The segment integration represents the shallowness in the segment system according to angular or metric depth rules. This analysis prevails compared to axial analysis due to a problem identified by Dalton (2001). He argues that, when using axial analysis, certain elements of Manhattan grid such as Broadway are not calculated in a way which represents its dense social activity. He suggests that Broadway should be calculated as one smooth line. This method has been identified later by Figueredo (2005) as "continuity lines". The method treats axial lines which intersect with negligible angles as single lines. Further studies on this type of analysis were made by Hillier, Turner, Yang and Park (2007). They have recognized that segment angular analysis operates in an analogous manner relative to continuity maps. Their method implies identifying the global geometric/topologic structure of the grid as the foreground structure of the network and metric depth as a way to identify patchworks localities of certain spatial identity. These localities constitute in total the background structure of the network and correspond to natural neighbourhoods in the city. They seem to be composed of clusters of short lines which cross in near right angles. The longer lines identify a global structure and behave similar to continuity lines. Hillier et. al. define these characteristics of the urban grid in probabilistic terms. On the one hand the longer the line the more likely it is to end in a nearly straight connection. On the other hand the shorter the line the more likely it is to end in a near right angle. These phenomena is marked in existing urban structures and might be a result of the generative process that Hillier (1996, 282) has suggested before. He recognizes the tendency of longer lines to continue straight and shorter lines to be blocked or intersected with other lines in right angles. This "centrality and extension" rule could have a contribution to the way cities have evolved. The current paper at hand draws on the methods developed by Hillier et. al. (2007) rather than the one developed by Figueredo (2005) because Hillier et. al. methods produce more distinguishable results in terms of the collective effect of segment elements within the urban network.

2.1. Manhattan grid: The spatial configurations of growth

Manhattan constitutes an interesting case study mainly because of its urban density which indicates to the success of its spatial urban environment along with other non-spatial factors. The grid has a significant value because it has suffered throughout its growth from two different growth processes. The first one has resulted from the formation of a bottom up emergent spatial structure which can be identified as the organic grid. This structure can be detected in the areas of the first settlements and later in the Washington Heights region. The second growth process has started with a top down planning decision which implies imposing a uniform grid on the vacant areas of the island region. This plan was commissioned in 1807 and adopted in 1811. Later on the grid has suffered from several deformations due to the topography of the island along with other reasons. Both growth processes have participated in the evolution of Manhattan grid which combines organic and uniform grid structures. This part of the paper will be directed towards understanding and analysing the dual transformation of these two grids which has led to the formation of the current state of Manhattan region.

The first approach towards understanding the regularities in Manhattan growth implies analysing the different stages of spatial growth. The growth process has been observed throughout the years; 1642, 1661, 1695, 1728, 1755, 1767, 1789, 1797, 1808, 1817, 1836, 1842, 1850, 1880, 1920, and 2009. The result of the angular segment integration analysis shows that the local integration increases as the system grows in the segment map (see figure1). This is calculated within 500 meter radius which almost equals five minutes' walking distance. A larger local radius such as radius 2000 meter would emphasize the same idea of the increase in integration values parallel to the growth process (see figure2). It can be noticed that the highest integration values concentrate in the downtown area whose deformed grid has grown naturally in a bottom up process. In general, the system seems to spread the high values of integration as it grows.

In another step towards analysing the urban structure of Manhattan the role of certain elements within the grid will be isolated and tested (see table1). Broadway Street -for example- is marked as a unique element within the existing spatial structure. This is mainly because it is the only diagonal element which crosses the planned uniform parts of the grid. The Central Park is another unique element forming a large gap in the geometrical centre of Manhattan. It is noticed that omitting Broadway for example decreases the local integration in several places along its path. By contrast filling Central Park with a uniform grid does not change the 500 meter radius case notably, but does extend the high values of integration in the downtown area towards the upper part of Manhattan in the 2000 meter radius case. Imposing a uniform grid all over Manhattan seems to spreads the high local and global integration values homogeneously in the whole area. The intensification of the uniform grid to match the intensity of the organic grid may give birth to new local centres. However, such alteration also draws higher global integration values towards the central cores of the grid areas. This particular grid behaviour proves the "paradox of centrality" identified in (Hillier 1996,266) as the tendency of the system to gain high integration values in the central core which comes together with a simultaneous loss of integration values in the periphery.

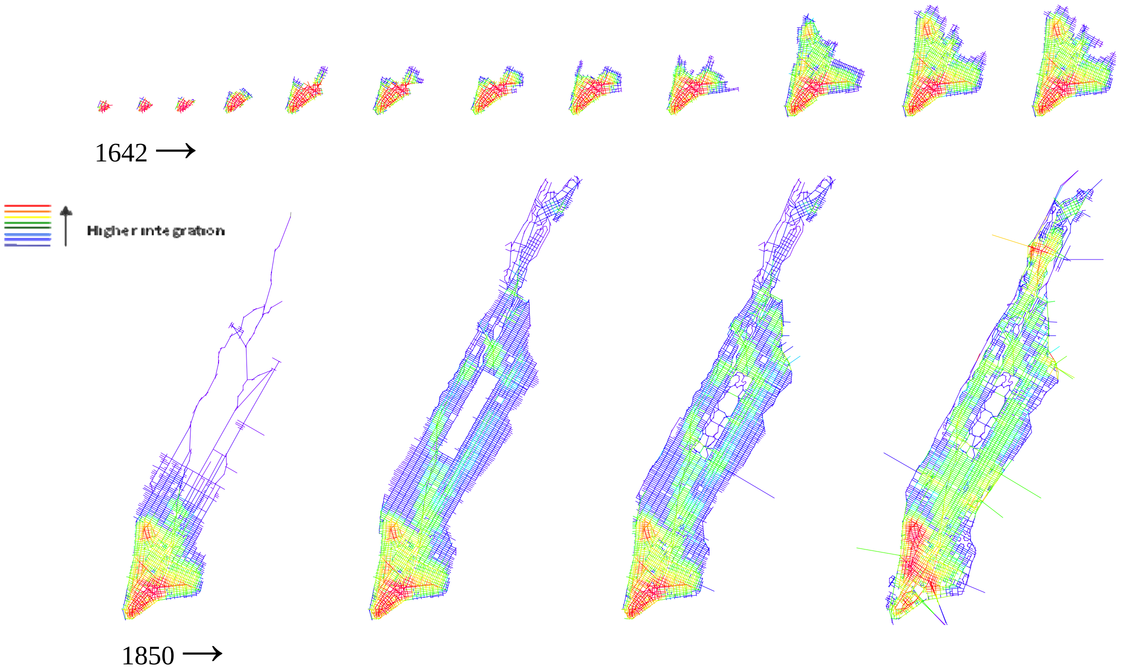


Figure 1
The evolution of local integration cores in Manhattan from the first settlement in 1642 to the recent state of the island. This is a Segment angular integration with 500m metric radius.

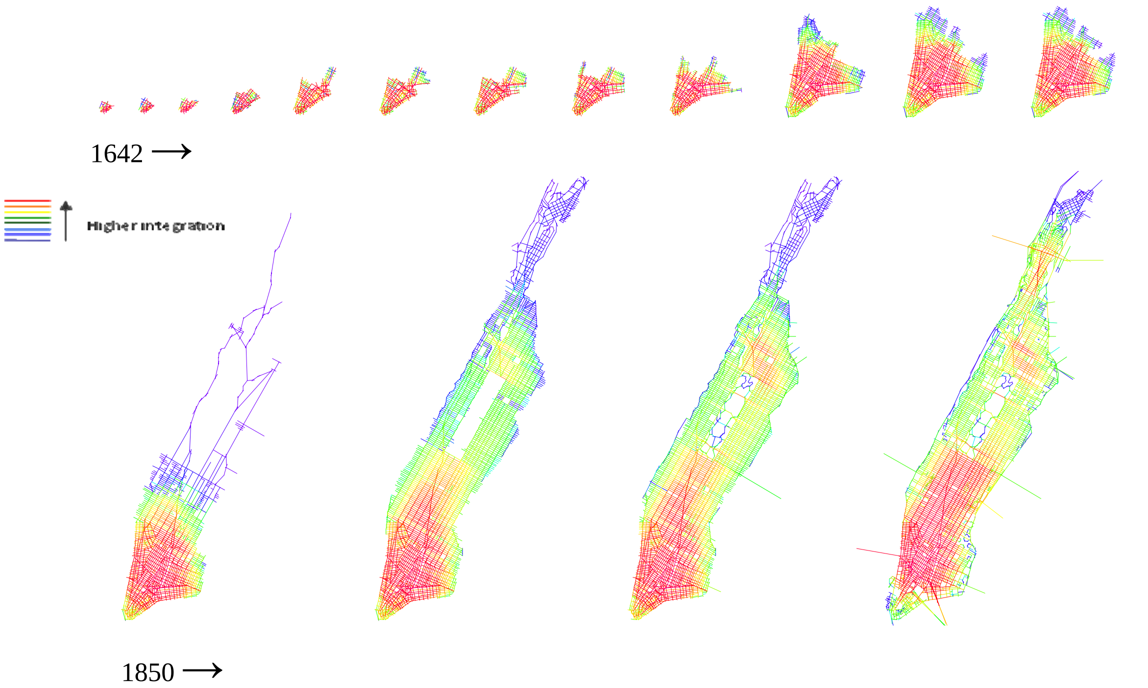


Figure 2
The evolution of global integration cores in Manhattan from the first settlement in 1642 to the recent state of the island. This is a Segment angular integration with 2000m metric radius.

In another approach to analyse the urban system of Manhattan we will consider the foreground versus background analysis related to Hillier et. al. research (2007). The foreground structure of Manhattan can be exposed in the analysis of segment angular depth (radius 0.5). This analysis as illustrated in figure 3a recognizes several significant lines in the spatial structure of Manhattan such as Broadway. The figure merely shows the last four phases of Manhattan growth. Yet the significance of the foreground structure is apparent even before the uniform part of the grid and the central park were built. This may emphasize the role of the longer lines in the foreground structure as the main generators of the grid. The foreground structure which represents the global configurations of the grid increases and extends as the system growths. In terms of the background structure; the sizes of the local clusters of shorter lines within a metric depth of radius 1000 shrink and concentrate slightly as the system grows (see figure3b). This might be interpreted in an escalating emphasis in the global and local spatial structures taking place throughout the spatial evolution process of Manhattan.

Overall, the three analytical attempts to understand the spatial structure of Manhattan underline several consistencies which are noticeable in the growth process of the urban region. One of these consistencies is that both local and global metric radiuses of segment angular integration values increase as the system grows. This increase in spatial integration seems to be directional. It generally starts from certain centres and grows in time sometimes producing new well-integrated centres. The second consistency is exposed when certain elements of the spatial structure of Manhattan are removed. This reveals that the top down planned grid has passed through several optimization iterations which deformed the uniform structure to allow the rise of new centres and reflect the functionality of certain areas spatially. The third consistency can be detected in the analysis of the foreground layer versus the background layer of an urban structure both defined by Hillier et. al. (2007). The foreground layer reflected in the angular depth analysis is distinguished in a global system of semi-continuous axial lines which become more apparent as the system grows. Similarly the background layer represented in the physical metrics of space becomes more distinguished resulting with local spots of patchworks in the grid structure.

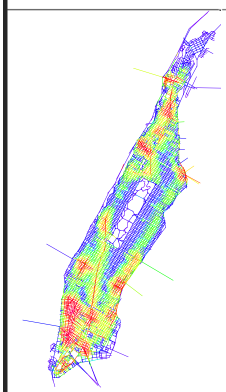
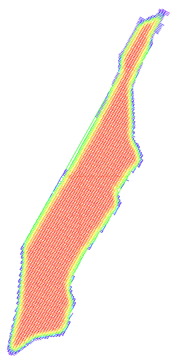
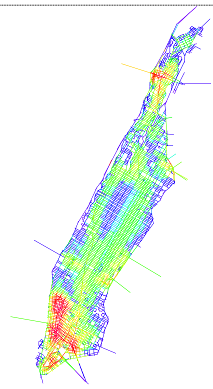
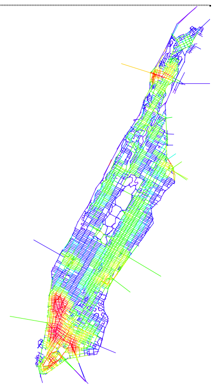
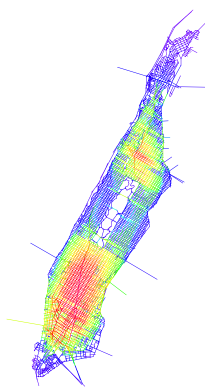
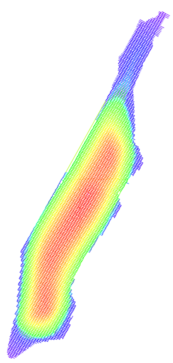
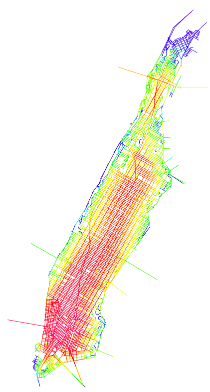
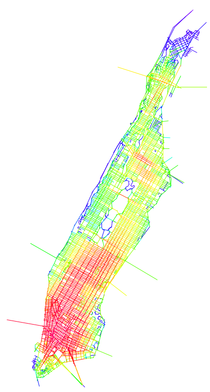
	Intensifying the uniform grid	Imposing uniform grid on Manhattan	Grid with Central Park filled	Grid with Broadway omitted
Segment angular integration with a metric radius of 500m				
Segment angular integration with a metric radius of 2000m				

Table 1

Testing unique spatial elements within Manhattan's grid

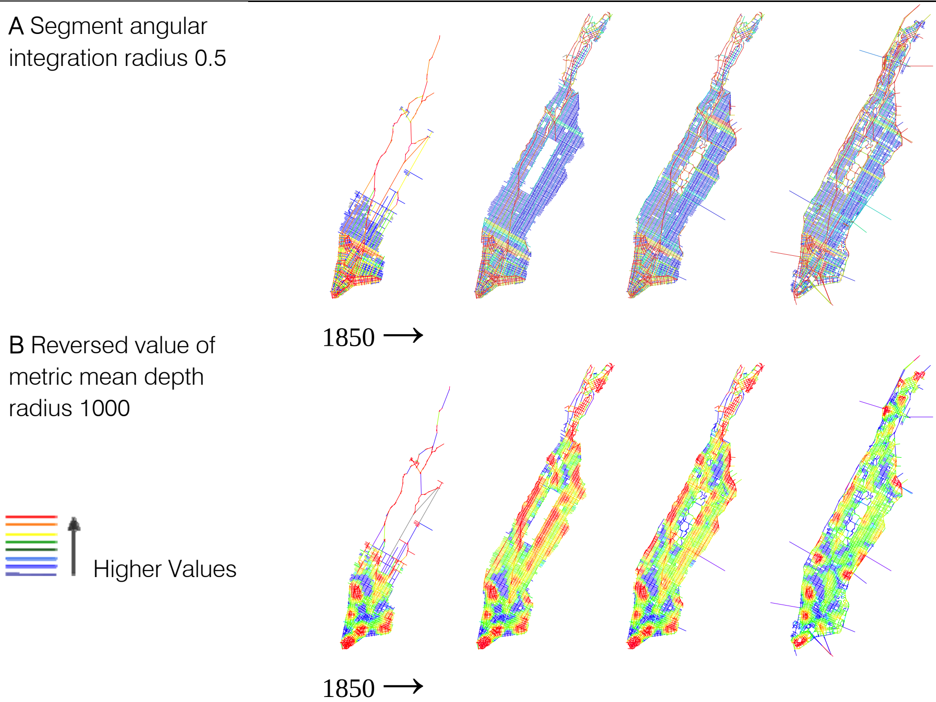


Figure 3:
Geometric and metric analysis of the last 4 phases of Manhattan’s urban growth.

2.2. Barcelona grid: The spatial configurations of growth
Barcelona as a spatial grid might illustrate a comparable example to that of Manhattan. The grid has also undergone several distinguished growth processes throughout a longer history of spatial growth. There might be two or even three divergent growth processes which congregated at a certain point to form the current state of the city. Similar to Manhattan the first one is an emergent product of a bottom up spatial growth which is distinguished as the organic grid of the old city. The second growth phase has been also initiated by imposing a uniform grid in a top down planning concept laid down in 1859. The building of this uniform grid called the "Ensanche" has taken place around the year 1891 and has been conducted in parallel to a third type of growth process. This process might be recognized as the natural growth of the suburban town centres which happened to be close to the periphery of the suggested uniform grid. The Current Spatial structure of Barcelona is a result of the intertwining between the old city, the emergent suburban growth and the pre-planned uniform grid.

In the first stage of the analytical study of Barcelona several phases of the city growth were highlighted and analysed spatially. Similar to Manhattan’s case, the choice of the growth phases was limited to the maps available at hand. The sequential dates of the maps are; 1260, 1290, 1698, 1714, 1806, 1855, 1891, 1901, 1920, 1943, 1970 and 2009. Through producing axial maps and analysing them some distinguished constancies started to appear particularly in the angular segment integration analysis. The analysis calculated within 500 meter radius shows that the old city maintains the highest local integration values as the spatial system grows (see figure 4). Yet, there are some distinct local centres which start to appear in the heart of the suburban town centres which once were scattered villages in the vicinity of the old city. The analysis calculated within radius 2000 meter reflects mainly the global effect of the collective behaviour of segment spatial elements. It proves the significant effect of introducing the uniform grid to the void connecting the old city and the scattered villages around (see figure 5). The high integration values which once have been majorly concentrated in the heart of the old city have spread to the uniform grid. This was accompanied with a decrease in the high integration values in the old city. High global integration values have also spread to the cores of the suburban town centres creating a network which connects all parts of the urban grid. As the spatial system grows the distinct features of the three different grids become more blurred and stronger spatial connections start to rise and become more vital in linking all the city parts.

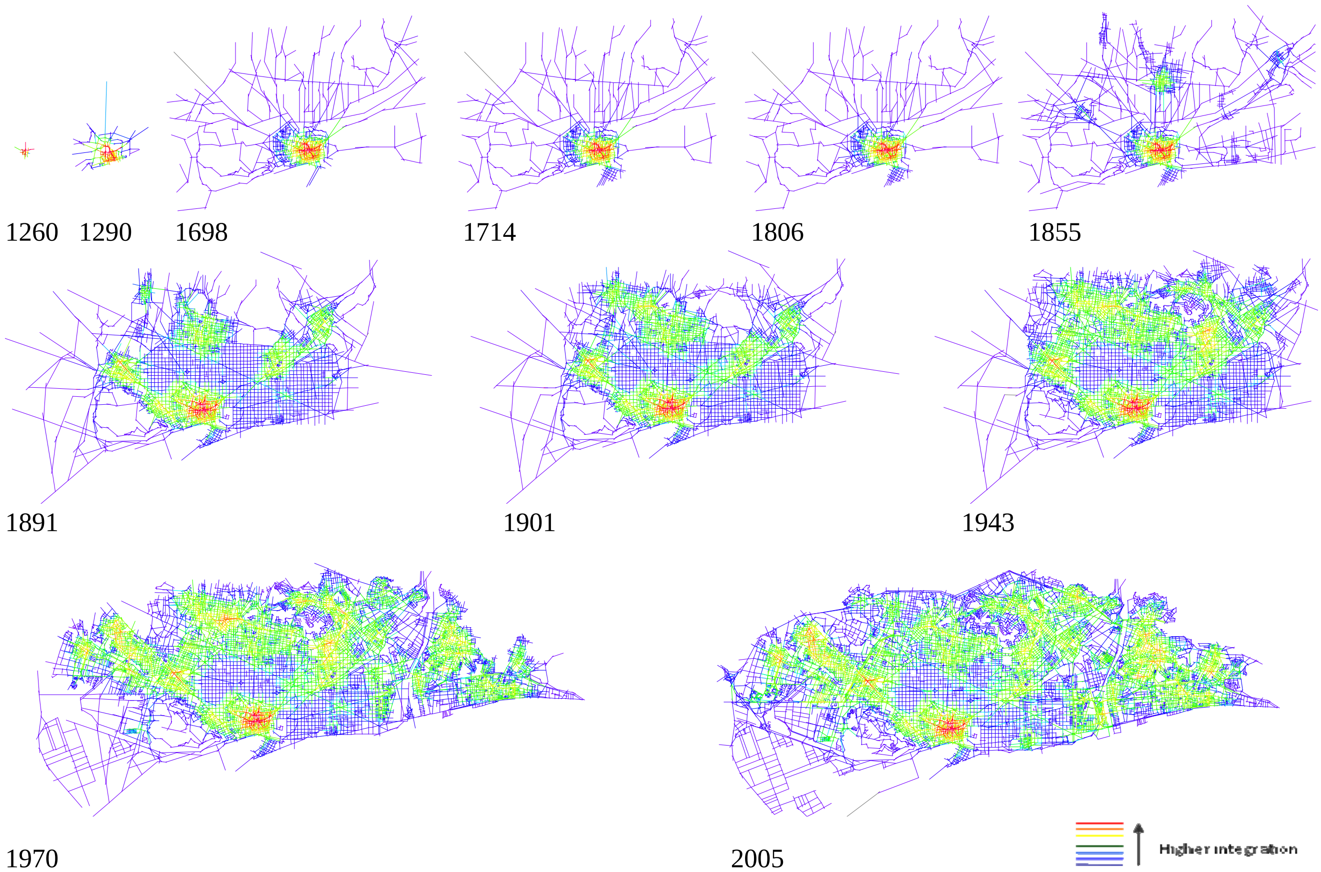


Figure 4
The evolution of Segment angular integration radius 500m metric in Barcelona.

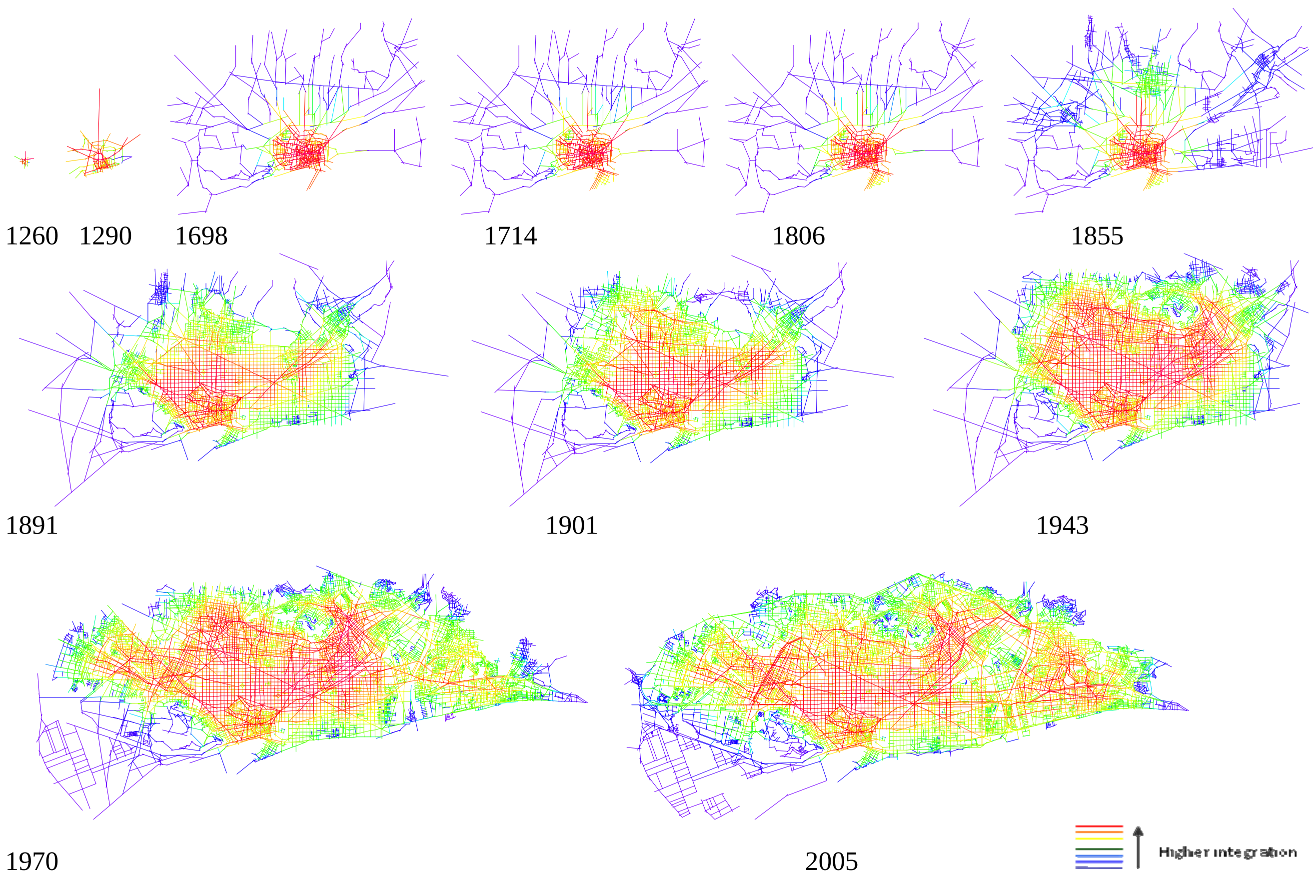


Figure 5
The evolution of Segment angular integration radius 2000m metric in Barcelona

In another attempt to reveal the embedded properties of Barcelona's urban structure, several elements were isolated and their absence and presence in the urban grid of the city was observed (see table2). The extension of the uniform grid to fill the Citadel park area attached to the borders of the old city did not make any difference in the local integration values on radius 500 meters while it fairly spreads the higher integration values to that area. The hill where currently the Olympic stadium is located forms also a significant break in the city grid. Its topography limits the possibility of extending the grid without substantially modifying it taking into considerations the differences in the ground levels. The analysis shows that if we consider the hill nonexistent and extend the uniform grid to fill its place the global integration values might spread there to a certain level but no difference would be observed on the local integration level. The filled area of the hill remains actually quite segregated on a radius of 500 meters. A considerable change in the integration values is also noticed when the old city is removed from the grid and its area is filled with uniform grid. This change emerges as the high global integration values decline dramatically and become far less distinguished in the area where the old city was located. The area appears to be completely segregated when it comes to local integration measures although the suburban centres gain more emphasis in terms of high integration values in this case. The distinctive diagonal lines in the uniform grid play an important role in connecting all the city part. This is not counting their added values of being urban buzz areas which witness high commercial activity, dense population residing along them and higher accounts of commuting passing through them compared to other city sectors. The exclusion of the diagonal lines in the grid does leave some impact on the spatial configurations of the segment map. This applies to both the local and global radiuses. The grid lacking the diagonal lines seem to be more disconnected. Some integrated areas along the diagonal lines disappear with them. Another experiment to test the uniform grid itself reveals that by doubling the density of the uniform grid a more concentration of high global integration values is brought about to the geometric centre of Barcelona's region and reduces integration values significantly in the periphery areas. This might be again explained by the "paradox of centrality"; an effect of maximising internal integration causing consequently a maximisation of external segregation. The difference on radius 500 meters appears as the crossing between the two main diagonals (Plaza De Las Glorias) becomes more highlighted with high integration values. Similar results are observed by extending this dense grid to substitute the old city structure. In this case the distinct integrated areas disappear from the old city region.

Similar to the methods used in Manhattan analysis this part of the analysis will focus on testing the angular depth representing the foreground structure of the city versus the physical metric measure representing the background structure of Barcelona. Both measures have been first implemented by Hillier et. al. methods (2007). The foreground structure of Barcelona calculated within radius 0.5 value highlights a set of continuous lines which together work as the main connecting elements in the urban structure as can be seen in figure 6a. These connecting elements are mainly made up of the diagonal lines along with some other long horizontal and vertical lines added to them at their ends a number of lines which almost extend their linear path or diverge from them with trivial angles. The lines in total form a foreground structure which ties all the city parts. This was the case with five selected phases observed during Barcelona's development. Physical dimensions were also studied in these particular phases and the metric analysis calculated within radius 1000 meters reveals patchworks in the grid with organic structures dissimilar from the regularity of the uniform grid. The patchworks manifested in figure 6b form in total the background structure of Barcelona. They include the old city part as can be detected in all the five phases of development studied added to it the suburban town centres and some other distinguished residential areas in the later stages of Barcelona's growth.

On the whole, the three stages of analyses expose several clues which help us understand the city of Barcelona in its current state as well as in the different growth processes the city has passed through. First, it might be evident in the local segment angular integration part that the old city preserves its high integration values and so do the cores of the suburban town centres which emerged in later stages of the city growth. The high global integration values are mostly visible in the uniform grid because of its connective attributes. It has attracted the higher values of global integration to it reducing the power of the globally integrated centre in the old city. The second stage of the analysis implies testing certain elements in the grid by isolating them to examine their own effect on the spatial structure of Barcelona. It seems to be evident that removing the Citadel Park, the Olympic hill or the old city from the grid and filling their areas with uniform grid leaves these areas quite segregated on the local integration level. The global integration analysis shows higher integration values in these areas apart from the old city case. In that particular case the old city area loses all the highly distinguished integrated lines and is filled instead with lower

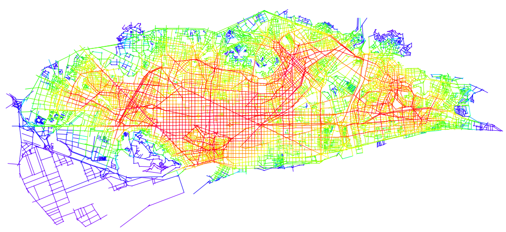
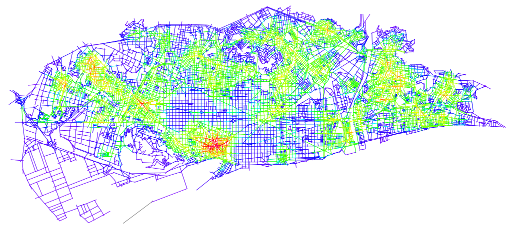
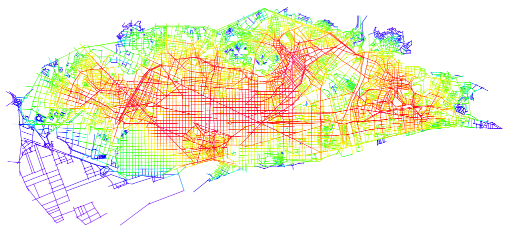
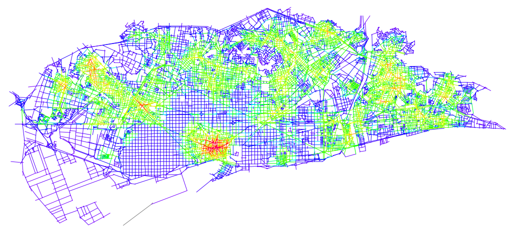
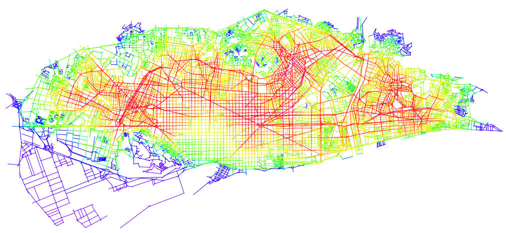
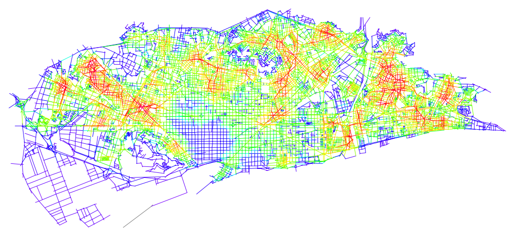
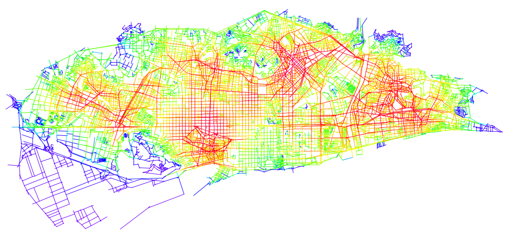
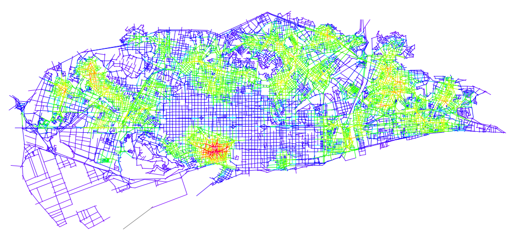
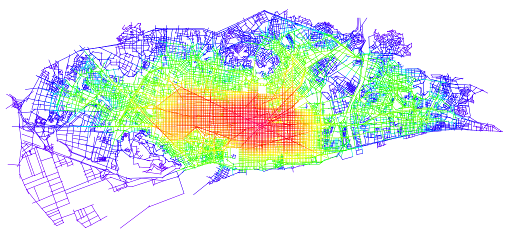
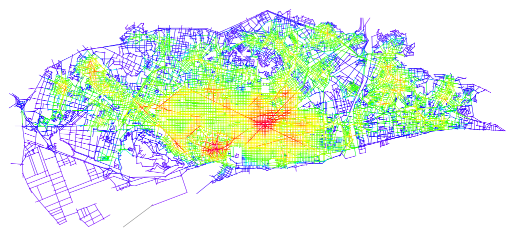
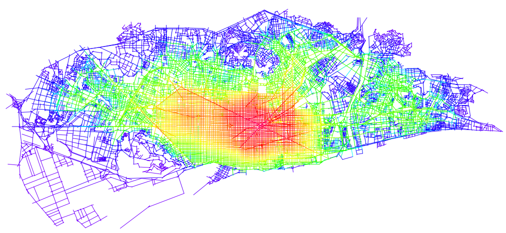
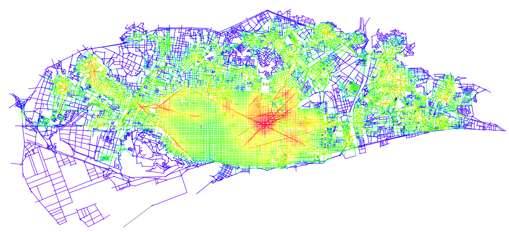
	Segment angular integration with a metric radius of 2000m	Segment angular integration with a metric radius of 500m
Citadel area filled with grid		
Olympic hill filled with uniform grid		
Old city area filled with uniform grid		
Diagonal axial lines omitted		
A denser uniform grid		
Old city area filled with dense grid		

Table 2

Testing unique spatial elements within Barcelona's grid

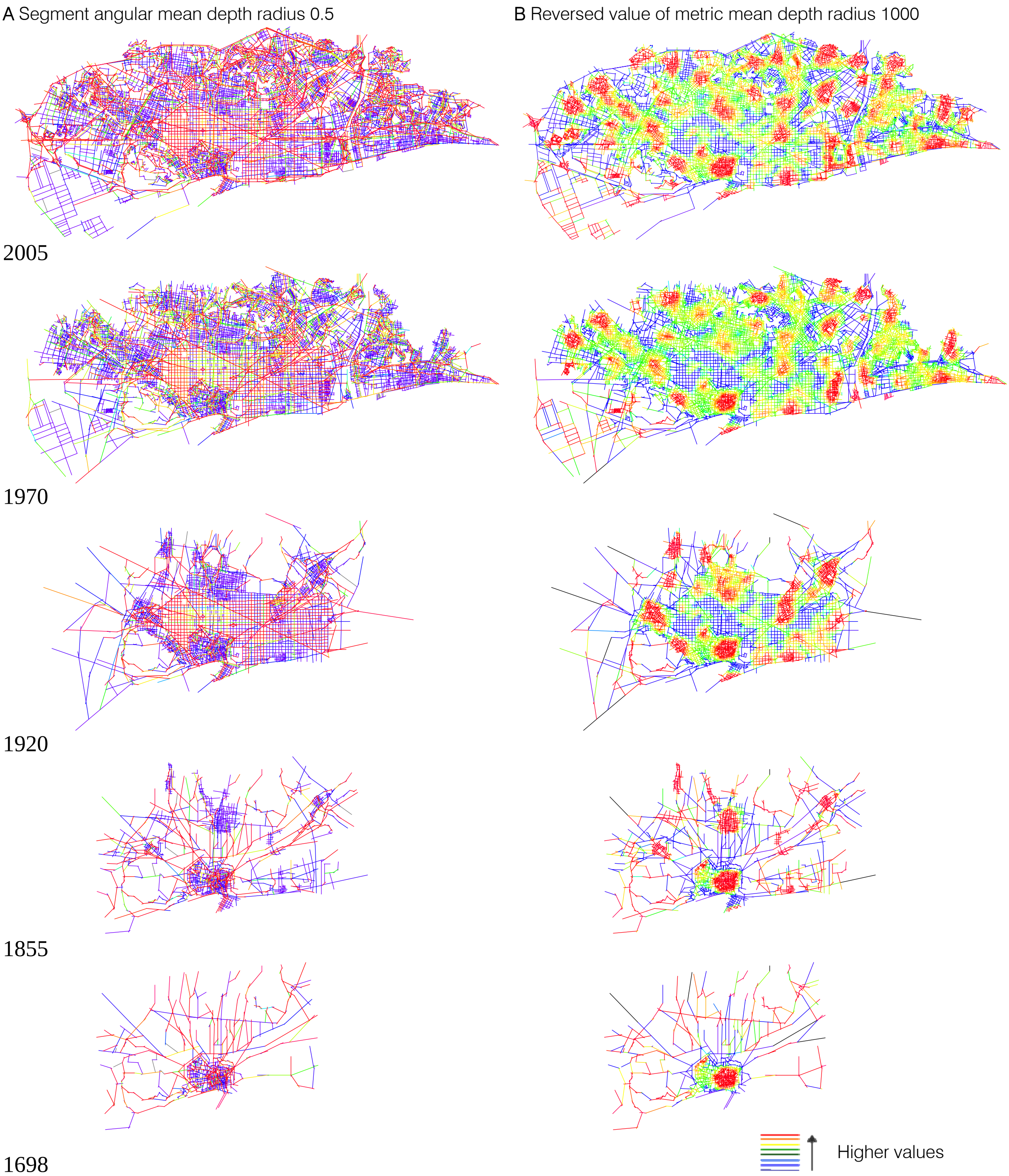


Figure 6
Geometric and metric analysis of five phases of Barcelona's urban growth.

integration values fading away outwards the uniform grid. The deletion of the diagonal lines leaves some negative impact on the grid causing a loss of connections and leads to lower local and global integration values in some areas which used to align the diagonals. Intensifying the uniform grid with a value 2:1 destroys the organic distribution of integration values and draws all the high global integration values to the uniform grid centre. It also concentrates the local integration values around the crossings of the diagonals. The third stage of the analysis provides us with a clear view regarding the foreground versus the background analysis of the city grid. The foreground representing the angular depth highlights a network of diagonal and perpendicular long lines which along with their semi continuous extensions define the global network pattern which connects all the city parts. The background analysis defines clusters of short lines forming patchworks in the areas where organic portions of the grid have emerged in the city structure throughout its development. As a consequence, these three stages of analysis might suggest that the natural emergent behaviour of the city grid has shaped Barcelona in its current state. The city was capable of adjusting its spatial elements, thus; creating its own organic centres and sub-centres along with its own network of semi continuous lines to connect all the city constituents.

3. Discussion and future studies

By careful considerations to both case studies, some comparable features can be detected not only in their historical growth pattern but also in the spatial configurations of their growth as well as their current state. Both Manhattan and Barcelona share similar growth patterns summarised by the bottom up organic growth and the top down planning decisions which resulted with imposing a uniform grid on the areas adjacent to the old organic structures. The third phase is the growth of the villages in the case of Barcelona and the Washington Heights area in Manhattan's case to interweave in a later stage with the uniform grid. The growth of both cities marked a shift in global integration heading towards the uniform grid area. At the same time the organic city structures in both cases have sustained their high local integration. The part of this current study which involved testing elements of both city grids has emphasized that both cities had their natural manner of self restructuring their spatial elements in order to reach a reasonably city-like pattern. This emergent behaviour of the two cities has occurred in spite of the planning authorities interfering in the growth of both cities. In both case studies the foreground versus the background analysis highlights similar characteristics. On the one hand the foreground analysis illustrates a distinctive network of continuous lines which branch and bond the city parts. On the other hand, clusters of shorter segments have appeared naturally in the background analysis representing most of the time cores of organic arrangements of neighbourhoods.

In general, this study considers each phase of city growth as a synchronous frame in the diachronic model of cities. Building upon that representation and considering the particularities of Manhattan and Barcelona as case studies, the comparison between the synchronic analyses of each phase in the development of Manhattan and Barcelona indicates to certain consistencies in the growth process. The revealed consistencies might indicate to a possible emergent model of both cities which might help us simulate their urban growth. This would be only possible if a set of rules could be extracted from the growth process. The potential rules can work in combination with Hillier's rule of "centrality and extension" (1996, 282); "don't block a longer local alignment if a shorter one can be blocked". First; the rules might be extracted from the edges of the growing system which means for example the range of angles in which the new lines will form with the older ones. This might vary according to the foreground and background structures. Second; the change in the foreground versus the background structures might indicate to distinctive generators versus generated elements in the grid. Third and most important; some of the generative rules could be extracted if a measure of change in the network configurations is introduced with which the forces of directional growth can be isolated. This is built on a suggested hypothesis that certain localities in the two dimensional network evolve potentials for directional growth through their temporary topological and geometric configurations. The directionality in this network might derive from the potentials of certain parts of the grid to grow and others to keep their status still which might create instabilities in the generative process reflected in the heterogeneity of the grid. A second hypothesis to extract some rules is applicable only to the pre-planned uniform grid and suggests that such grid passes through several optimization stages to deform into an adaptive model which differentiates certain functionalities and evolves new local centres. A third hypothesis suggested in this research implies that as the system grows the global topo/geometric configurations strengthen and the local physical configurations concentrate their values. These three hypotheses will lead probably to identify a set of generative rules which contribute to the evolution of existing spatial structures. The efficiency of the expected rules would be tested by applying them to a growth simulation and comparing the results with the existing grid. Future studies will therefore look into enhancing the properties of the growing networks by optimizing spatial depth. In case the emergent model was successful for Manhattan and Barcelona, it will be generalized through making further case studies on other cities. Nonetheless, the expected answer might be complex and relative to different cities or different grids. The generic model will be later implemented in evolving emergent models which are case sensitive to cities and spatial structures of certain configurations. Such emergent models will help understanding the evolution process of cities and might aid the strategic spatial planning of new integrated urban structures.

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